

SOIL AND COMMUNITY CHARACTERISTICS ASSOCIATED WITH *HAZARDIA ORCUTTII* (ASTERACEAE)

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ABSTRACT

Hazardia orcuttii (A. Gray) Greene is a 5–10 dm tall perennial shrub that is native to coastal sage scrub communities of southern California and northern Baja California. This species was listed as threatened by the California Department of Fish and Game in 2002 and is a federal candidate species, and the only known population in the U.S. is on a 1.6 ha mesa located in Encinitas, California. Very little is known about the general ecology of this species, thus, the goal of this research was to characterize the basic soil physical and chemical properties and plant community characteristics associated with this species. Research was conducted between January 2004 and July 2005 in 12.56 m² randomly-located plots that either contained or lacked *H. orcuttii*. Soil in plots containing *H. orcuttii* had significantly higher clay, soil organic matter, total N, and soil moisture content than plots lacking *H. orcuttii*, while plots lacking *H. orcuttii* had significantly more surface litter content. Significant differences were also observed in plant species abundance between plots containing and lacking *H. orcuttii*, indicating fundamental differences in plant community composition associated with patches of *H. orcuttii*. Our data support the notion that *H. orcuttii* is a soil endemic; however, it is unclear whether *H. orcuttii* prefers soil richer in clay or is restricted to these soils because of other factors. Given the restricted nature of *H. orcuttii*, and the proximity of the extant population to residential areas, habitat protection from human degradation and fire should be a high priority.

RESUMEN

Hazardia orcuttii (A. Gray) Greene es un arbusto perenne que mide 5–10 dm de alto que es nativo a la comunidad perteneciente de la salvia chaparral costeno en el sur de California y el la parte fronterizo de Baja California Norte. Esta especie fue enumerada como una que esta bajo de amenaza por el Departamento de California pescaderia y casa en el 2002, y la unica poblacion en los Estados Unidos, esta en una mesa de 1.6 ha ubicado en Encinitas, Calif. Poco se sabe sobre la ecologia general de esta especie, asi, el fin de esta inverstigacion era de caracterisar las propiedades basicos físicos y químicos de la tierra y las carecteristicas planta asociadas con esta comunidad de esta especie. Investigaciones fueron condujidos entre Enero 2004 y Julio 2005 en 12.65 m² en parcelas establecidas al azar unos conteniendo y otros careciendo *H. orcuttii*. Tierra en parcelas conteniendo *H. orcuttii* tenian significativamente alto niveles de barro, mater organica del suelo, nitrogeno total, y contenido de humedad del suelo que las parcelas careciendo *H. orcuttii* tenian significatimante mas contenido de revoltura al superficie. Diferencias significativas fueron observados en la abundancia de especie de plantas entre parcelas conteniendo y careciendo de *H. orcuttii*, indicando diferencias esenciales en el compuesto de la comunidad de las plantas asociado con parches de *H. orcuttii*. Nuestros datos apoyan la nocion que *H. orcuttii* es endemica de la tierra sin embargo, no es claro si *H. orcuttii* prefiere tierra rico en barro o esta limitado a esta tierra por otros elementos. Dado por la naturaleza limitado de *H. orcuttii*, y la cercania de la proximidad de una poblaciones que existe en areas residenciales, proteccion de los habitos degradantes causados por la humanidad y el fuego derian ser de alta prioridad.

Key Words: Asteraceae, biodiversity, chaparral, coastal sage scrub, human impacts, soil, threatened plants species.

Habitat loss reduced the extent of coastal sage scrub by 72% from 1970–1990 (Pryde 1992), causing some plant and animal species to become threatened or endangered. One such species, *Hazardia orcuttii* (A. Gray) Greene (*Orcutt's Hazardia*), is a 5–10 dm tall resinous evergreen shrub in the Asteraceae family that is native to maritime sage scrub-chaparral communities of southern California and northern Baja California (Hickman 1993) and was listed by the California Department of Fish and Game as threatened in August 2002 (Gogol-Prokurat and Osborne 2002).

Specimens collected between 1920 and 1985 indicate that the distribution of *H. orcuttii* ranged from Encinitas, California to Punta Colonet, Baja California, Mexico. The current distribution is uncertain (Gogol-Prokurat and Osborne 2002) and only two of the 13 previously documented Mexican populations have been located as of 2004. This plant naturally occurs in only one documented location in the United States, on a 1.6 ha mesa (elev. 90–120 m) approximately 5 km from the Pacific coast near Lux Canyon in the Manchester Conservation Area in Encinitas,

California. Moreover, plants are distributed in patches that occupy an approximately 0.15 ha area located in the SW corner of the mesa. The number of plants in this population has been estimated to be 50–700 (Oberbauer 1981; Gogol-Prokurat and Osborne 2002; Vourlitis et al. 2006). The population appears to be long established (based on field observations of plant size and woodiness), and voucher specimens from 1979 indicate that the population has been established at Lux Canyon for at least 30 yr. *Hazardia orcuttii* occurs in a sage scrub-chaparral habitat along with other perennial species such as *Rhus integrifolia* (Nutt.) W. H. Brewer & S. Watson., *Adenostoma fasciculatum* Hook. & Arn., and *Artemisia californica* Less. (nomenclature according to Hickman 1993).

Little is known about the basic ecology, including population structure and habitat requirements of *H. orcuttii*; however, previous research suggests that *H. orcuttii* is restricted to soils with higher clay content (Oberbauer 1981). Research designed to determine the basic ecological requirements of *H. orcuttii* is needed to conserve this species (Gogol-Prokurat and Osborne 2002). Given the current status of this species the main objectives of this research were to characterize the soil physical and chemical properties and the plant community associated with the extant *H. orcuttii* population at Lux Canyon.

MATERIALS AND METHODS

Site Description

Field measurements were conducted from January 2004–July 2005 at Lux Canyon (33°1'48"N, 117°15'6"W) in the Manchester Conservation Area in Encinitas, CA. Lux Canyon is approximately 5 km east of the ocean at an elevation that ranges from 10 m above sea level in the valley bottom to 100 m on the mesa top (Center for Natural Lands Management (CNLM) 2005). Vegetation consists of Diegan sage scrub and southern maritime chaparral (CNLM 2005), and the main soil types consist of Altamont clay (Typic chromoxerert) on the mesa top and a loamy, alluvial Huerhuero complex (Typic natrixeralf) on the eroded slopes and valley bottoms (Bowman 1973). Climate data obtained since 1998 from the National Oceanic and Atmospheric Administration for Palomar Airport in Carlsbad, California located approximately 13 km north of Lux Canyon with similar coastal exposure indicates a maritime Mediterranean-type climate with warm-dry summers and cool-wet winters. Average annual rainfall is approximately 200 mm (7.9 in.) and average annual maximum and minimum temperature is 19.8 and 12.7 °C, respectively. The

wettest month is February with 64 mm of rainfall and the driest month is August with 0.4 mm rainfall.

Field Sampling and Data Collection

Field plots consisting of 12.56 m² permanent circular quadrats were randomly established in sub-sites containing *H. orcuttii* (n = 13 plots; hereafter referred to as "*H. orcuttii* plots") and in adjacent sub-sites lacking *H. orcuttii* (n = 10 plots; hereafter referred to as "*non-H. orcuttii* plots"). As mentioned above, sub-populations of *H. orcuttii* are restricted to a 0.15 ha portion of the mesa top. Within this area circular plots were established within patches containing *H. orcuttii* and patches lacking *H. orcuttii* using a random coordinate system. We attempted to pair each plot containing *H. orcuttii* with a plot lacking *H. orcuttii*, but the spatial distribution of paths and shape of the vegetation fragments precluded an adequate paired-design resulting in unbalanced replication for *H. orcuttii* and *non-H. orcuttii* plots.

Measurements of plant species abundance were conducted over a total of 4 sample campaigns (January and July of 2004 and 2005) in the *H. orcuttii* plots and *non-H. orcuttii* plots described above. All individuals rooted within each plot (Chapman 1976; Barbour et al. 1999) were counted and measured for width along 2-axes (the maximum width and the axis perpendicular to the maximum width) and height from the ground surface to the top of the shrub (Bonham 1989).

Soil and surface organic matter (litter, which is dead plant matter >1 mm in diameter) was collected in April 2004 to coincide with the spring growing season and the main period of seed germination. Samples were obtained from the *non-H. orcuttii* plots (n = 10) and a subset of the *H. orcuttii* plots (n = 10) to preserve as much as possible the paired-sampling design between *H. orcuttii* and *non-H. orcuttii* plots. Surface litter was collected within a 312.5 cm² rectangular quadrat that was centered on a randomly chosen point in each plot. After litter removal, soil samples were obtained from surface (0–10 cm) and subsurface (30–40 cm) soil layers using a 173.5 cm³ bucket auger. Soil samples were transferred from the core samplers to polyethylene sample bags and immediately returned to the lab and stored at 4 °C until analysis.

Sample Processing and Data Analysis

Plant species density was quantified as the number of individuals per species per unit plot area and cover was quantified as the area of each shrub species per plot divided by the area of the

plot. The area (A) of each individual shrub was calculated as $\pi D^2/4$, where D is the average diameter of each individual calculated from the measurements of maximum and perpendicular width. Frequency of occurrence was calculated as the number of plots that a particular species was encountered. Indices of relative abundance were calculated from the estimates of absolute abundance by dividing a given absolute abundance for a particular species by the total abundance of all species. These relative indices were combined to yield an estimate of the index of relative importance (IRI), which was calculated as the sum of the individual relative density, cover, and frequency of occurrence indices (Chapman 1976; Barbour et al. 1999).

Soil samples were sieved to remove rocks and organic matter ≥ 2 mm in size prior to laboratory analyses. Litter samples were passed through a 1 mm sieve to remove mineral debris, dried at 70°C for 1 wk, weighed, and ground to pass through a 40 mesh sieve. Total N and P content of soil and litter was quantified using micro-Kjeldahl methods (Bremner 1996). Percent gravimetric soil water was calculated as $[(M_f - M_d)/M_d]*100$ where M_f was the fresh mass of soil and M_d was the mass of soil after drying at 105°C (Robertson et al. 1999). Percent soil organic matter was quantified by combusting soil at 700°C for 1 h in a muffle furnace (Nelson and Sommers 1996). Soil bulk density was calculated as the mass of dry soil per unit volume (Robertson et al. 1999). Soil particle size distribution was measured using the Bouyoucos hydrometer method (Gee and Bauder 1986).

Cluster analysis was used to assess the similarity in community composition between the habitats containing and lacking *H. orcuttii*. For this analysis, the plot values of the IRI of each species were used to determine the degree of similarity between discrete plots, and the "Euclidian Distance" method was used to determine the relative distance between each plot (Hintze 2005). Soil physical and chemical data were analyzed using a 2-way analysis of variance (ANOVA) with site (*H. orcuttii* vs. non-*H. orcuttii* plots) and depth (0–10 and 30–40 cm) treated as fixed effects. Data were tested for normality and heteroscedasticity using the Anderson-Darling and Levene's tests, respectively. Data violating assumptions of normality and heteroscedasticity were LN-transformed to fulfill the assumptions of ANOVA. Cluster analysis and ANOVA were performed using NCSS (version 2004, Kaysville, Utah, USA). Differences in litter pool biomass and N and P content between *H. orcuttii* and non-*H. orcuttii* plots were analyzed with a randomized-t-test (Sokal and Rohlf 1995) using MS-Excel (Christie 2004).

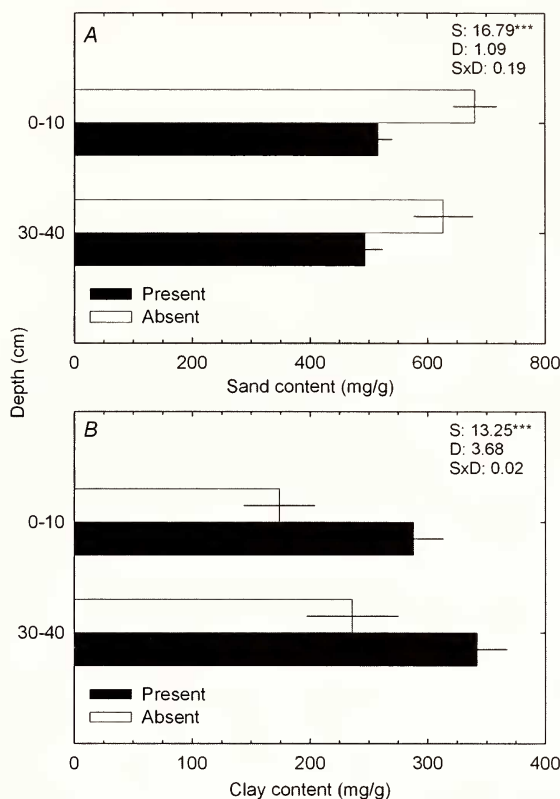


FIG. 1. The mean (\pm SE) sand (A) and clay (B) content of soil in plots where *Hazardia orcuttii* was present (closed bars; $n = 10$ plots) or absent (open bars; $n = 10$ plots) at different soil depths. Also shown are the results of a 2-way ANOVA (F -statistic) where sub-site (habitat) and depth were fixed effects ($df = 1,36$ for sub-site (S), depth (D), and the sub-site \times depth interaction (S*D)). *** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$.

RESULTS

Soil Physical and Chemical Properties

Sand content of surface (0–10 cm) and sub-surface (30–40 cm) soil in areas lacking *H. orcuttii* was significantly higher than in areas containing *H. orcuttii* (Fig. 1A; $F_{1,36} = 16.79$; $P < 0.001$). Clay content of soil in areas with *H. orcuttii* was significantly higher than in areas lacking *H. orcuttii* (Fig. 1B; $F_{1,36} = 13.25$; $P < 0.005$). Differences in particle size distribution were large enough that plots containing *H. orcuttii* were characterized as having a sandy clay loam soil while plots lacking *H. orcuttii* were characterized as having a sandy loam soil. Plots containing *H. orcuttii* also had significantly higher soil water content (Fig. 2A), especially in the sub-surface, and a significantly higher soil organic matter (SOM) content (Fig. 2B). Total soil N content (Fig. 3A) was significantly higher in plots containing *H. orcuttii*, especially in the surface soil

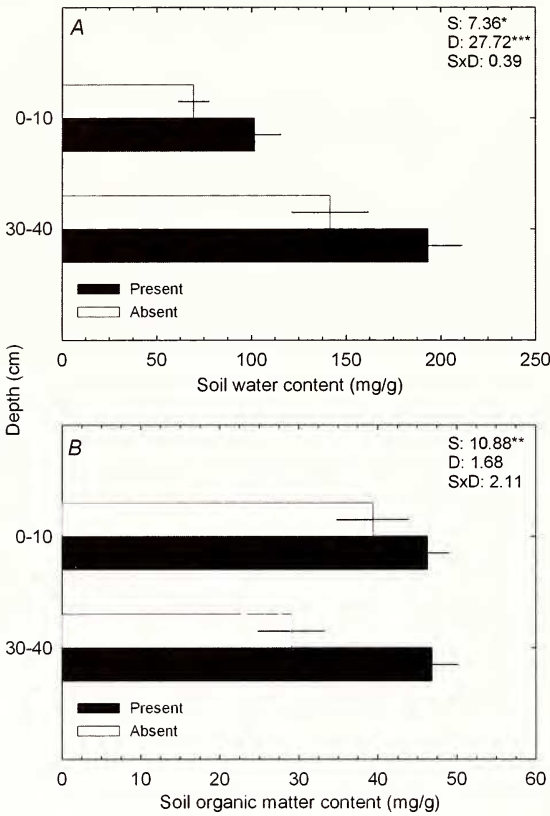


FIG. 2. The mean (\pm SE) water (A) and organic matter (B) content of soil in plots where *Hazardia orcuttii* was present (closed bars; $n = 10$ plots) or absent (open bars; $n = 10$ plots) at different soil depths. Also shown are the results of a 2-way ANOVA (F -statistic) where sub-site (habitat) and depth were fixed effects ($df = 1,36$ for sub-site (S), depth (D), and the sub-site X depth interaction (S*D)). *** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$.

layer. In contrast, total soil phosphorus (P) content was similar for plots with and without *H. orcuttii* (Fig. 3B).

The N and P concentration of surface litter was not statistically different between *H. orcuttii* and non-*H. orcuttii* habitats; however, because surface litter biomass was nearly 3-times higher in non-*H. orcuttii* plots ($P = 0.003$; Fig. 4A), litter N and P pools sizes were significantly higher in non-*H. orcuttii* plots (Fig. 4B, C). Thus, while *H. orcuttii* plots had significantly higher SOM and total soil N, plots lacking *H. orcuttii* had a significantly higher surface litter pool and litter N content.

Community Composition

Cluster analysis of the sample plots indicated two discrete vegetation assemblages (Fig. 5) based on the importance values (IRI) of the plant species. The first group consisted of all of the

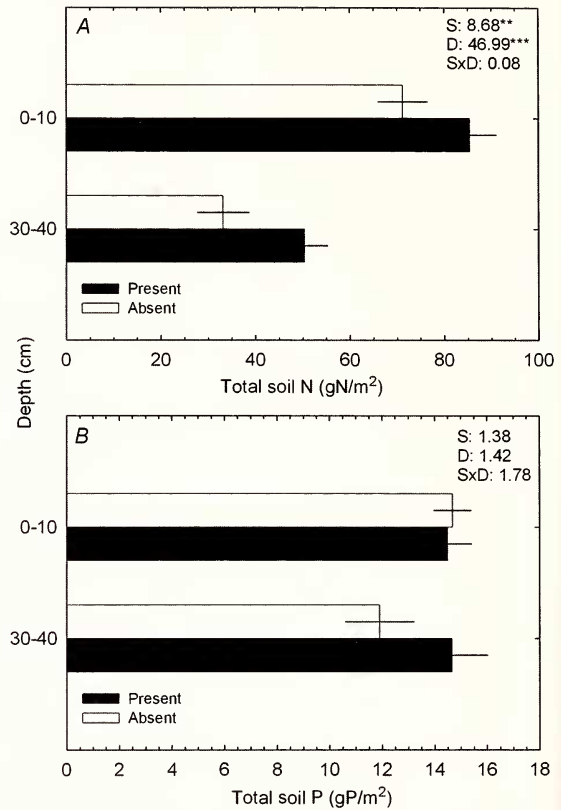


FIG. 3. Mean (\pm SE) total soil N (A) and P (B) content in plots where *Hazardia orcuttii* was present (closed bars; $n = 10$ plots) or absent (open bars; $n = 10$ plots) at different soil depths. Also shown are the results of a 2-way ANOVA (F -statistic) where sub-site (habitat) and depth were fixed effects ($df = 1,36$ for sub-site (S), depth (D), and the sub-site X depth interaction (S*D)). *** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$.

plots lacking *H. orcuttii* ("B" plots; Fig. 5), while the second major grouping consisted of the plots where *H. orcuttii* was present ("A" plots; Fig. 5). This clustering described the maximum variation in the sample plots ($r = 0.89$), and indicated two discrete sub-communities at Lux Canyon.

Some species were common to both sub-communities, including *Adenostoma fasciculatum*, *Artemisia californica*, *Eriogonum fasciculatum* Benth., *Quercus dumosa* Nutt., *Rhus integrifolia*, and *Deinandra fasciculata* (DC.) Greene (Table 1). However, *A. fasciculatum*, *Q. dumosa*, and *R. integrifolia* had higher mean values of IRI over the 2-year field study in non-*H. orcuttii* plots, while *E. fasciculatum*, *Dudleya edulis* (Nutt.) Moran, and *D. fasciculata* were more abundant in *H. orcuttii* plots (Table 1). Other species including *Mimulus aurantiacus* Curtis, *Xylococcus bicolor* Nutt., *Yucca schidigera* Ortgies, and *Y. whipplei* Torr. were conspicuously lacking in *H. orcuttii* plots, while *Lotus scoparius* (Torr. & A. Gray) Otlely, *Ferocactus viridescens* (Torr. & A.

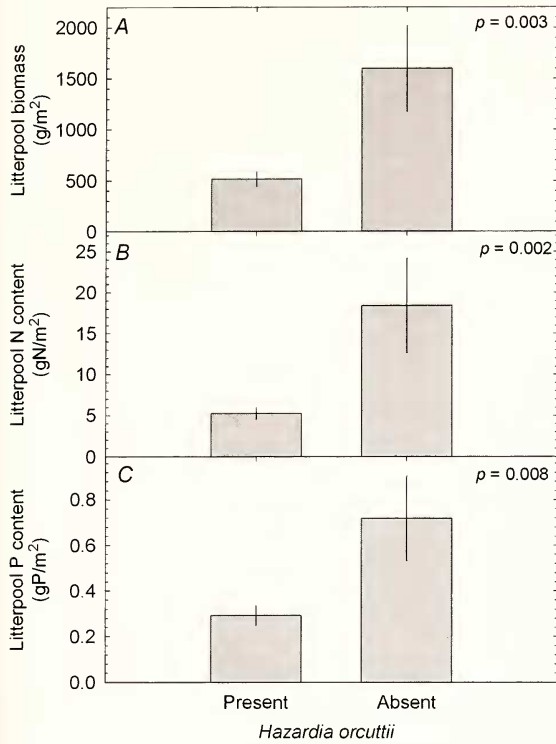


FIG. 4. Mean (\pm SE) litter biomass (A) and total litter N (B) and P (C) pool sizes in plots where *Hazardia orcuttii* was present or absent ($n = 10$ plots per subsite). Also shown are the results of a randomized t-test, where the probability of committing a type-I error (P-value) was calculated over 1000 iterations.

Gray) Britton & Rose, and *Baccharis pilularis* DC. were observed only in *H. orcuttii* plots (Table 1).

Significant differences in total density and cover were also apparent between *H. orcuttii* and non-*H. orcuttii* plots (Fig. 6). Plots lacking *H. orcuttii* had significantly higher cover in 2004 (Fig. 6A), which explains in part the significantly higher surface litter pool (Fig. 4A). Plots lacking *H. orcuttii* also had significantly lower density than *H. orcuttii* plots during each measurement campaign (Fig. 6B) suggesting that, on average, non-*H. orcuttii* plots were dominated by fewer but larger shrubs. One of the most abundant shrubs in plots lacking *H. orcuttii* was *A. fasciculatum* (Table 1), which is a chaparral shrub that can reach heights of 2 m and an area of 3–4 m² (Munz 1974; Riggan et al. 1988).

Temporal variations in stand cover and density were relatively higher in *H. orcuttii* plots than in non-*H. orcuttii* plots. For example, *H. orcuttii* plots experienced a nearly 4-fold increase in stand cover (Fig. 6A) and a more than 5-fold increase in stand density (Fig. 6B) between July 2004 and January 2005. Over the same period plots lacking *H. orcuttii* experienced no increase in stand cover (Fig. 6A) and a 2-fold increase in stand density (Fig. 6B). Thus, *H. orcuttii* plots experienced larger temporal variation in overall plant species abundance than non-*H. orcuttii* plots, which may have implications for *H. orcuttii* recruitment and survival.

Temporal variation in the index of relative importance (IRI) of the six dominant shrub species (excluding *H. orcuttii*) present in both

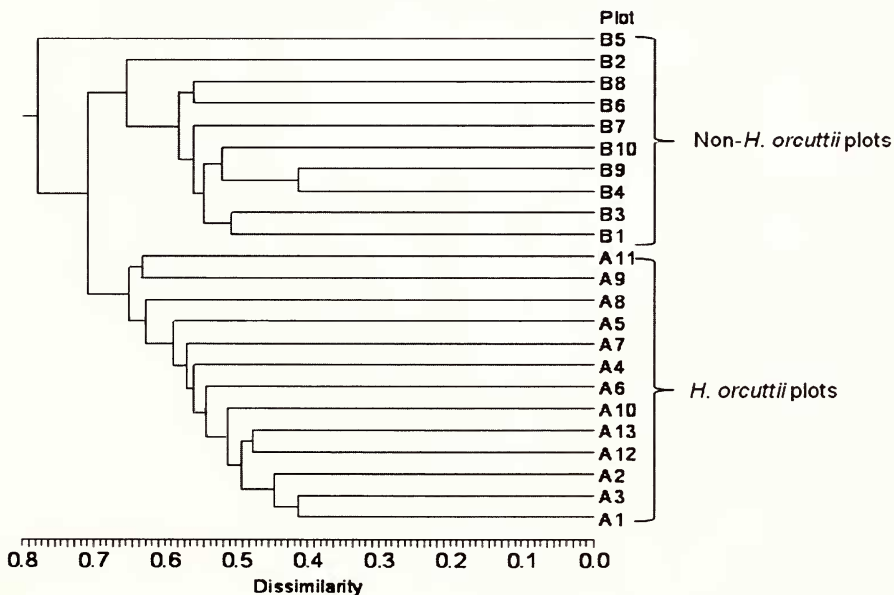


FIG. 5. Cluster analysis of the index of relative importance (IRI) values of plant species observed in plots containing (A1-13) and lacking (B1-10) *Hazardia orcuttii*.

TABLE 1. MEAN (\pm 1SD) INDEX OF RELATIVE IMPORTANCE (*IRI*) FOR ALL SPECIES OBSERVED IN 12.56 m² PLOTS CONTAINING (PRESENT; *n* = 13) AND LACKING (ABSENT; *n* = 10) *HAZARDIA ORCUTTII* AT LUX CANYON, ENCINITAS, CALIFORNIA. Data were collected over 4 sampling campaigns conducted in January and July of 2004 and 2005. *IRI* was multiplied by 100; — not observed. Nomenclature and habitat data according to Hickman (1993).

Species	<i>Hazardia orcuttii</i>	
	Present	Absent
<i>Adenostoma fasciculatum</i> Hook. & Arn.	28.9 \pm 23.3	66.8 \pm 9.8
<i>Artemisia californica</i> Less.	64.6 \pm 36.4	49.9 \pm 8.9
<i>Dudleya edulis</i> (Nutt.) Moran	13.8 \pm 5.2	5.3 \pm 3.2
<i>Eriogonum fasciculatum</i> Benth.	42.7 \pm 22.1	14.0 \pm 3.7
<i>Hazardia orcuttii</i> (A. Gray) Greene	32.4 \pm 15.5	—
<i>Ferocactus viridescens</i> (Torr. & A. Gray) Britton & Rose	7.3 \pm 2.0	—
<i>Minulus aurantiacus</i> Curtis	—	37.6 \pm 4.1
<i>Opuntia littoralis</i> (Engelm.) Cockerell	1.5 \pm 1.1	5.5 \pm 0.5
<i>Quercus dumosa</i> Nutt.	2.2 \pm 1.1	17.0 \pm 4.5
<i>Rhus integrifolia</i> (Nutt.) W. H. Brewer & S. Watson	13.4 \pm 7.6	47.6 \pm 18.7
<i>Xylococcus bicolor</i> Nutt.	—	2.8 \pm 0.7
<i>Yucca schidigera</i> Ortgies	—	8.6 \pm 4.1
<i>Yucca whipplei</i> Torr.	—	2.8 \pm 1.9
<i>Lotus scoparius</i> (Torr. & A. Gray) Ottley	8.2 \pm 3.4	—
<i>Deinandra fasciculata</i> (DC.) Greene	55.6 \pm 79.2	9.9 \pm 12.5
<i>Marah macrocarpus</i> (Greene) Greene	—	3.9 \pm 5.4
<i>Dichondra occidentalis</i> House	—	1.1 \pm 2.2
<i>Centaurium venustum</i> (A. Gray) B. L. Rob.	—	1.7 \pm 3.4
<i>Anagallis arvensis</i> L.	0.3 \pm 0.6	0.6 \pm 1.3
<i>Cholorgahum parviflorum</i> Wats.	5.8 \pm 11.5	10.9 \pm 21.8
<i>Zigadenus fremontii</i> (Torr.) S. Watson	0.4 \pm 0.9	—
<i>Dichelostemma pulchella</i> (Salisb.) Heller	0.9 \pm 1.7	0.5 \pm 1.0
<i>Baccharis pilularis</i> DC.	0.4 \pm 0.8	—
<i>Eriophyllum confertiflorum</i> (DC.) A. Gray	—	0.6 \pm 1.2
<i>Gnaphalium californicum</i> DC.	0.4 \pm 0.7	1.8 \pm 3.7
<i>Gnaphalium</i> sp.	0.6 \pm 1.3	0.6 \pm 1.2
<i>Cryptantha</i> sp.	—	0.5 \pm 1.1
<i>Stephanomeria</i> sp.	0.5 \pm 0.9	—
Thistle	8.6 \pm 16.0	5.8 \pm 7.0
Unknown annual	0.9 \pm 1.7	1.2 \pm 1.4
Unknown herbaceous perennial	—	0.6 \pm 1.2
Unknown grass	10.7 \pm 18.7	2.3 \pm 3.3

plot types revealed substantial changes in shrub species composition over 2004–2005, especially in the *H. orcuttii* plots (Fig. 7). In *H. orcuttii* plots, *A. fasciculatum* and *D. fasciculata* exhibited 3–4 fold increases in *IRI* during the study period, while *A. californica* and *E. fasciculatum* experienced a 2–3-fold decline in *IRI* (Fig. 7). In contrast, plots lacking *H. orcuttii* experienced substantially less temporal variation in relative abundance; however, *R. integrifolia* was an obvious exception (Fig. 7). These data indicate rapid and dynamic species turnover in *H. orcuttii* plots and more stable community dynamics in non-*H. orcuttii* plots.

DISCUSSION

Soil Physical and Chemical Properties

Some soil physical and chemical properties at Lux Canyon were significantly different between plots containing and lacking *H. orcuttii*. One

potentially key difference was soil texture, where *H. orcuttii* plots had significantly higher clay content and lower sand content than non-*H. orcuttii* plots (Fig. 1). This observation is supported by previous research and is consistent with the notion that *H. orcuttii* may be a soil endemic (Oberbauer 1993). Gravimetric soil water content was significantly higher in *H. orcuttii* plots (Fig. 2A), which presumably reflects the higher clay content of the soil. Soil texture controls a variety of processes that control plant species distribution, including soil water holding capacity, nutrient retention, organic matter stabilization, seed germination, and seedling recruitment (Baskin and Baskin 1990; Oberbauer 1993; Schimel et al. 1985; Kluse and Doak 1999; Walck et al. 1999; Hook and Burke 2000). However, it is unclear why *H. orcuttii* at Lux Canyon is restricted to soil with higher clay content. For example, percent germination of *H. orcuttii* seeds was actually higher in soil types that had lower clay content (Miller 2008); thus, *H. orcuttii* is

apparently not restricted to soil with higher clay content because of seed germination.

Hazardia orcuttii plots had higher soil organic matter (SOM) content than non-*H. orcuttii* plots (Fig. 2B), which presumably indicates differences in plant species composition and/or rooting depth between habitats (Jobbágy and Jackson 2000). The increase in SOM was apparently not due to an increase in aboveground litter input because the surface litter pool was nearly 3-fold lower in *H. orcuttii* plots (Fig. 4A). Rather, *H. orcuttii* plots had a higher abundance of shrubs associated with coastal sage scrub (Table 1), which typically have a shallower, more horizontally-distributed root system than species characteristic of evergreen chaparral (Hellmers et al. 1955). *Hazardia orcuttii* plots also had higher total soil N, suggesting higher overall fertility compared to non-*H. orcuttii* plots (Marion and Black 1988). Given that SOM represents a large pool of N in terrestrial soils (Hook and Burke 2000), these results presumably reflect the significantly higher SOM content observed in *H. orcuttii* plots.

Surface litter was more than 3-times higher in non-*H. orcuttii* plots, which has important implications for the germination and recruitment of *H. orcuttii*. For example, the germination and seedling recruitment of *Chorizanthe pungens* Benth. var. *hartwegiana* Reveal and Hardham (Polygonaceae) is reportedly inhibited by chaparral vegetation, possibly as a result of allelopathy and/or the development of a larger surface litter pool that alters the microclimate and reduces light availability at the soil surface (Kluse and Doak 1999). Results from germination experiments indicate that percent germination of *H. orcuttii* seeds was significantly lower in complete darkness, which may simulate light conditions under a deep surface litter layer (Miller 2008). While there are substantial seasonal variations in the production of aboveground litter and the size of the surface litter pool in coastal sage scrub and chaparral (Vourlitis et al. 2009), the difference in the litter pool between plots containing and lacking *H. orcuttii* observed in April coincides with the most active time for seed germination for chaparral and coastal sage shrubs. The relatively larger surface litter pool observed in non-*H. orcuttii* plots may inhibit seed germination and/or seedling recruitment, which may be one important mechanism causing *H. orcuttii* to be restricted to more clay-rich soils.

Community Composition

Our results indicate fundamental differences in species composition between *H. orcuttii* and non-*H. orcuttii* plots (Fig. 5). These differences are presumably due in part to spatial variations in

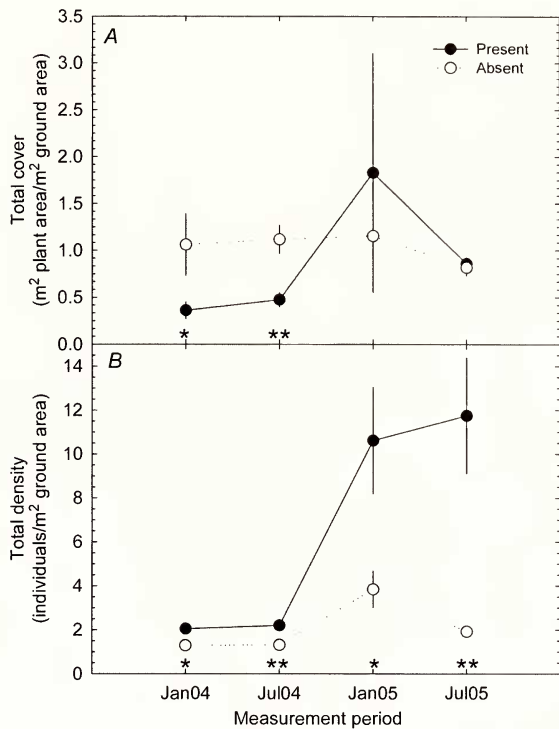


FIG. 6. Average (\pm SE) total shrub cover (A) and density (B) in plots containing *Hazardia orcuttii* (closed-circles, solid-lines; $n = 13$ plots) and plots lacking *H. orcuttii* (open-circles, dotted-lines; $n = 10$ plots). Differences in mean cover and density between habitat types were assessed using a two-sample t-test. * $P < 0.05$; ** $P < 0.01$.

soil texture, which exerts a strong influence on soil water availability and plant species distribution (Westman 1981). *Hazardia orcuttii* plots had significantly lower cover and higher density (Fig. 6) and more rapid and dynamic species turnover (Fig. 7) than plots lacking *H. orcuttii*, and it is possible that these interspecific dynamics affect *H. orcuttii* recruitment, survival, and fecundity. For example, the higher temporal variation in species composition in *H. orcuttii* plots implies higher variation in the intensity of competitive interactions, availability of "safe sites" important for *H. orcuttii* recruitment, and/or available resources (Menges 1990; Watson et al. 1994; Kluse and Doak 1999; Walck et al. 1999). Similar interspecific controls on plant growth, fecundity, and recruitment have been observed for other Asteraceae including *Coreopsis lanceolata* L. (Folgate and Scheiner 1992), *Ratibida columnifera* (Nutt.) Wootton & Standl. (Vargas-Mendoza and Fowler 1998), *Solidago shortii* Torr. & A. Gray (Walck et al. 1999) and *Deinandra conjugens* (D. D. Keck) B. G. Baldwin (Bauder et al. 2002). Presumably similar processes may be important in limiting the local distribution of *H. orcuttii*.

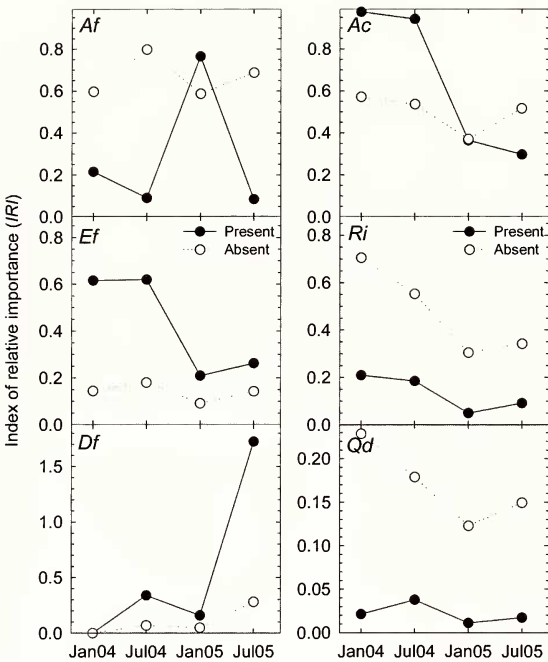


FIG. 7. Temporal variation in the index of relative importance (IRI) for the six dominant plant species *Adenostoma fasciculatum* (Af), *Artemisia californica* (Ac), *Eriogonum fasciculatum* (Ef), *Rhus integrifolia* (Ri), *Deinandra fasciculata* (Df), and *Quercus dumosa* (Qd) in plots containing *H. orcuttii* (closed-circles, solid-lines) and plots lacking *H. orcuttii* (open-circles, dotted-lines). Together, individuals of these species made up 70% of all shrubs and perennials observed in both plot types. Note the difference in scale for Df and Qd.

Conclusions and Conservation Recommendations

Rabinowitz et al. (1986) define a rare species as one that has a restricted geographic range, narrow habitat tolerance, and/or low local abundance. *Hazardia orcuttii* appears to possess all three of these traits. For example, the only known extant U.S. population of *H. orcuttii* is restricted to a 1.6 ha mesa near Lux Canyon, Encinitas, CA. Within this narrow geographic range, *H. orcuttii* individuals appear to be restricted to patches of soil with high clay content, but it is unclear whether *H. orcuttii* is restricted to clay soils because of intrinsic (i.e., seed germination and/or recruitment) or extrinsic (interspecific competition) factors. Knowledge of why *H. orcuttii* is restricted to more clay-rich soils will undoubtedly inform and improve the success of future conservation efforts. Estimates from 2002 indicated approximately 600 plants at Lux Canyon (Gogol-Prokurat and Osborne 2002), while more recent estimates (Vourlitis et al. 2006) indicated a population size of 510 individuals, suggesting that the population has declined since 2002. The low local abundance, restricted geo-

graphic range, and narrow habitat tolerance suggest that *H. orcuttii* is rare by all criteria.

Protection of Lux Canyon from human degradation and fire should be a high priority. The Lux Canyon site is used for recreation purposes, and human activities lead to the creation of paths, trampling and damage of vegetation, accumulation of waste, and urban runoff. These threats increase the potential for catastrophic fire, which can either damage or completely eliminate that only known U. S. population of *H. orcuttii*.

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LITERATURE CITED

- BARBOUR, M. G., J. H. BURK, W. D. PITTS, F. S. GILLIAM, AND M. W. SCHWARTZ. 1999. Terrestrial plant ecology, 3rd ed. Benjamin Cummings, Menlo Park, CA.
- BASKIN, J. M. AND C. C. BASKIN. 1990. Seed germination ecology of poison hemlock, *Conium maculatum*. Canadian Journal of Botany 68:2018–2024.
- BAUDER, E. T., J. SNAPP-COOK, AND J. SAKRISON. 2002. Ecology and management of *Deinandra conjugens* (D. D. Keck) B.G. Baldwin (Otago Tarplant). Final Report. California Department of Fish and Game, Region 5, San Diego, CA.
- BONHAM, C. D. 1989. Measurements of terrestrial vegetation. John Wiley & Sons, Inc., New York, NY.
- BOWMAN, R. 1973. Soil survey of San Diego County, California. Soil Conservation Service and United States Department of Agriculture, Washington, DC.
- BREMNER, J. M. 1996. Nitrogen-total. Pp. 1085–1122 in D. L. Sparks, A. L. Page, P. A. Helmke, R. H. Loeppert, P. N. Soltanpour, A. Tabatabai, C. T. Johnson, and M. E. Sumner (eds.), Methods of soil analysis: Part 3. Chemical Methods. Soil Science Society of America Book Series No. 5, Soil Science Society of America, Inc., Madison, WI.
- CENTER FOR NATURAL LANDS MANAGEMENT (CNML). Website <http://www.cnml.org/cms/> [accessed 27 January 2010].
- CHAPMAN, S. B. 1976. Methods in plant ecology. Halsted Press, Inc., New York, NY.
- CHRISTIE, D. 2004. Resampling with Excel. Teaching Statistics 26:9–14.
- FOLGATE, L. A. AND S. M. SCHEINER. 1992. Distribution of a restricted locally abundant species: effects of competition and nutrients on *Coreopsis lanceolata*. American Midland Naturalist 128:254–269.
- GEE, G. W. AND J. W. BAUDER. 1986. Particle-size analysis. Pp. 383–412 in A. Klute (ed.), Methods of soil analysis: part 1 physical and mineralogical methods, 2nd ed. Soil Science Society of America

- Book Series No. 5. Soil Science Society of America, Inc., Madison, WI.
- GOGOL-PROKURAT, M. AND M. OSBORNE. 2002. Report to the Fish and Game Commission on the status of Orcutt's *Hazardia* (*Hazardia orcuttii*). Status Report 2002-01. California Department of Fish and Game, Habitat Conservation Planning Branch, Sacramento, CA.
- HELLMERS, H., J. S. HORTON, G. JUHREN, AND J. O'KEEFE. 1955. Root systems of some chaparral plants in southern California. *Ecology* 36:667-678.
- HICKMAN, J. C. (ed.). 1993. The Jepson manual: higher plants of California. University of California Press, Berkeley, CA.
- HINTZE, J. 2005. NCSS and PASS. Number Cruncher Statistical Systems, Kaysville, UT.
- HOOKE, P. B. AND I. C. BURKE. 2000. Biogeochemistry in a shortgrass landscape: control by topography, soil texture, and microclimate. *Ecology* 81:2686-2703.
- JOBÁGY, E. G. AND R. B. JACKSON. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications* 10:423-436.
- KLUSE, J. AND D. F. DOAK. 1999. Demographic performance of a rare California endemic, *Chorizanthe pungens* var. *hartwegiana* (Polygonaceae). *American Midland Naturalist* 142:244-256.
- MARION, G. M. AND C. H. BLACK. 1988. Potentially available nitrogen and phosphorus along a chaparral fire cycle chronosequence. *Soil Science Society of America Journal* 52:1155-1162.
- MENGES, E. S. 1990. Population viability analysis for an endangered plant. *Conservation Biology* 4:52-62.
- MILLER, J. 2008. Reproductive biology and germination requirements of the California state threatened species *Hazardia orcuttii* (Asteraceae). M.S. thesis. California State University, San Marcos, CA.
- MUNZ, P. A. 1974. A flora of southern California. University of California Press, Berkeley, CA.
- NELSON, D. W. AND L. E. SOMMERS. 1996. Total carbon, organic carbon, and organic matter. Pp. 961-1010 in D. L. Sparks, A. L. Page, P. A. Helmke, R. H. Loeppert, P. N. Soltanpour, A. Tabatabai, C. T. Johnson, and M. E. Sumner (eds.), *Methods of soil analysis: part 3. Chemical methods*. Soil Science Society of America Book Series No. 5, Soil Science Society of America, Inc., Madison, WI.
- OBERBAUER, T. 1981. Noteworthy collections: *Hazardia orcuttii* (Gray) Greene (Compositae). *Madroño* 28:38.
- . 1993. Soils and plants of limited distribution in the Peninsular Ranges. *Fremontia* 21:3-7.
- PRYDE, P. R. 1992. San Diego: an introduction to the region. Kendall-Hunt Publishing Co., Dubuque, IA.
- RABINOWITZ, D. H., S. CAIRNS, AND T. DILLON. 1986. Seven forms of rarity and their frequency in the flora of the British Isles. Pp. 182-204 in M. E. Soule (ed.), *Conservation biology: the science of scarcity and diversity*. Sinauer Associates, Inc., Sunderland, MA.
- RIGGAN, P. J., S. GOODE, P. M. JACKS, AND R. N. LOCKWOOD. 1988. Interaction of fire and community development in chaparral of southern California. *Ecological Monographs* 58:155-176.
- ROBERTSON, G. P., D. C. COLEMAN, C. S. BLEDSOE, AND P. SOLLINS (eds.). 1999. *Standard soil methods for long-term ecological research*. Oxford University Press, New York, NY.
- SCHIMEL, D., M. A. STILLWELL, AND G. R. WOODMANSEE. 1985. Biogeochemistry of C, N, and P in a soil catena of the shortgrass steppe. *Ecology* 66:276-282.
- SOKAL, R. R. AND F. J. ROHLF. 1995. *Biometry*. 3rd ed. W. H. Freeman and Company, San Francisco, CA.
- VARGAS-MENDOZA, M. C. AND N. L. FOWLER. 1998. Resource-based models of competitive interactions. I. Intraspecific competition in *Ratibida columnifera* (Asteraceae). *American Journal of Botany* 85:932-939.
- VOURLITIS, G. L., J. KIRKER, AND K. COLER. 2006. Research for the management and conservation of Orcutt's *Hazardia* (*Hazardia orcuttii*). Final Report. California Department of Fish and Game, Habitat Conservation Planning Branch, Sacramento, CA.
- , S. C. PASQUINI, AND R. MUSTARD. 2009. Effects of dry-season N input on the productivity and N storage of Mediterranean-type shrublands. *Ecosystems* 12:473-488.
- WALCK, J. L., J. M. BASKIN, AND C. E. BASKIN. 1999. Effects of competition from introduced plants on establishment, survival, growth and reproduction of the rare plant *Solidago shortii* (Asteraceae). *Biological Conservation* 88:213-219.
- WATSON, L. E., G. E. UNO, N. A. MCCARTY, AND A. B. KORNEKVEN. 1994. Conservation biology of a rare plant species *Eriocaulon kornickianum* (Eriocaulaceae). *American Journal of Botany* 81:980-986.
- WESTMAN, W. E. 1981. Factors influencing the distribution of species of Californian coastal sage scrub. *Ecology* 62:439-455.